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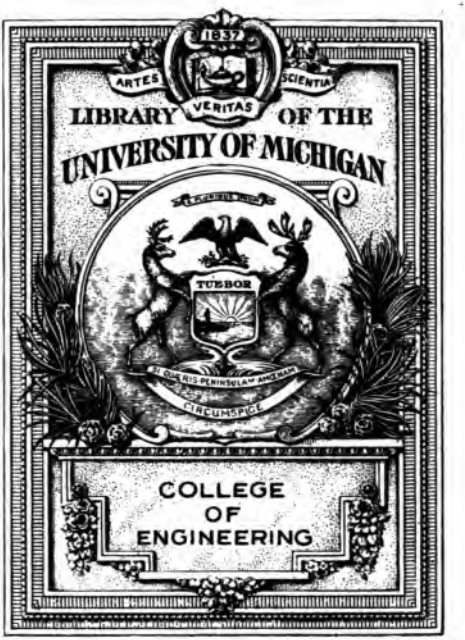
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LONGMANS, GREEN, AND CO.,
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'WATER SUPPLY' AND 'DRAINAGE'

SYSTEMATISED AND SIMPLIFIED

BY

C. E. HOUSDEN

LATE SUPERINTENDING ENGINEER, PUBLIC WORKS DEPARTMENT, INDIA, AND SANITARY ENGINEER TO THE GOVERNMENTS OF BURMA AND EASTERN BENGAL AND ASSAM

WITH PLATES

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1912

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PREFACE

THIS small volume is in reality a supplement to the author's 'The Precise Calculation of Pipe Drain and Sewer Dimensions,' but can, if so desired, be used without any reference thereto—the help of many error-saving Tables, which find a place in the original work, being however in such case not available. It illustrates how the preparation of a project for either 'Water Supply' or 'Drainage' can be systematised and simplified by a consideration of the 'hydraulic gradients' of the entire system and by their employment in ascertaining precisely from the parent work and the Tables therein, or very approximately from the two *Scales* in the present work, the dimensions of the pipes, drains or sewers needed for the particular scheme under consideration.

As these dimensions can in either case be ascertained for *any* reasonable slope in the water surface and practically *any* required discharge by simple multiplication and a consideration of the Tables or Scales, this work should be a special help to small corporations, colonists, planters, estate agents, and all who cannot afford or obtain other professional advice and assistance.

To the trained engineer, both the original work and this supplement thereto will, it is hoped, be also useful as time and labour-saving aids to the ready and accurate solution of hydraulic problems, using at will any desired generally recognised coefficient.

C. E. H.

LONDON : *July 1912.*

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'WATER SUPPLY' AND 'DRAINAGE' SYSTEMATISED AND SIMPLIFIED

CHAPTER I

THE SCALES, HOW FRAMED

IF—

L is the length of a pipe or drain *in feet*,

and—

H is for it the available head *in feet*,

then—

S 'the slope in the water surface' or 'the hydraulic gradient' of the pipe or drain will practically $= \frac{H}{L}$.

Also if—

F is the discharge required, or under supply, in a pipe or drain in cubic feet per second (Cusecs),

and—

G is the similar discharge in gallons per minute (Galmins),

then—

The values of $\frac{L}{H}F^2$ and $\frac{L}{H}G^2$ ascertained as explained in the original work deduced from Professor Unwin's coefficients for *clean* pipes (adopted as a standard) will, in round numbers for all gradients and discharges and for different diameters, in

inches (d), be those shown in the accompanying full and inset scales respectively.

2. The value of $\frac{L}{H}F^2$ for a 48 in. diameter deduced from Kutter's $n = 0{\cdot}013$ is about 2,200,000, corresponding to the value of $\frac{L}{H}F^2$ for a 47 in. diameter on the standard scale; the *addition* to the latter diameter will thus be 1 in., as shown by a dot on the full scale—with which use bookmark.

The value of $\frac{L}{H}F^2$ for a 48 in. diameter from Unwin's coefficients for *incrusted* pipes is 1,128,000, corresponding to the value of $\frac{L}{H}F^2$ for a 41·5 in. diameter on the standard scale; the required *addition* will now be $48 - 41{\cdot}5 = 6{\cdot}5$ in. as shown by a dot on the full scale.

The value of $\frac{L}{H}F^2$ for a 48 in. diameter from Kutter's $n = 0{\cdot}010$ is found to be 3,900,000, corresponding on the standard scale to a 52·5 in. diameter; the *deduction* to be made from the latter diameter will thus be $52{\cdot}5 - 48 = 4{\cdot}5$ in., as shown by a dot on the full scale.

The value of $\frac{L}{H}G^2$ for a 4 in. diameter with $n = 0{\cdot}013$ is 360,000, corresponding to the value of $\frac{L}{H}G^2$ for a clean $3\frac{1}{2}$ in. diameter; the required addition to the latter diameter will thus be $\frac{1}{2}$ in., as shown on the small inset scale. For an incrusted pipe it will be about 1 in.

3. The values of $\frac{L}{H}F^2$ and $\frac{L}{H}G^2$ have been similarly ascertained for all the coefficients shown on the two scales, and the additions and deductions needed indicated as before by 'dots.'

The 'dots' for each separate coefficient when connected together are found to lie in practically a straight line as will be seen from the full scale.

The reliability of the two scales so obtained is demonstrated and their application explained later on.

The relative conditions to which the different coefficients best apply are indicated on the scales.

CHAPTER II

A SCHEME FOR A WATER SUPPLY

THE actual *conditions and requirements* of a 'Water Supply Scheme' sufficient for 390,000 persons at the rate of 1 cusec for 10,000 persons (equivalent to 54 gallons per head in 24 hours or 27 gallons in 12 hours) being those indicated in the upper half of Plate III, in which the reduced levels at the source of supply and at the terminal points of the pipes from which water has to be drawn as well as the full discharge required in each pipe in cusecs are shown, it follows that as it is generally necessary in the case of town supplies to have everywhere a surplus head of about 100 feet above ground level to allow of water being laid on to houses, and to provide an ample supply for protection against fire, we shall want a surplus head of about 100 feet at D the highest point in the system (R.L. 100 at ground level) at which water is needed.

[For estate plantation and other small supplies a surplus head of 10 feet should suffice.]

The point D is 22,000 feet from the source of supply A (R.L. of water surface 400).

The 'average hydraulic gradient' for the three pipes AB, BC, CD, from A to 100 feet above D will thus be $400 - 200 = 200$ feet in 22,000 feet or 1 in 110.

[For a small water supply it would be 1 in $\frac{22000}{290}$ or 1 in 76.]

The required *clean* diameters (Unwin) of the three pipes will then for a gradient of 1 in 110 from the full scale be—

For pipe AB as $\frac{L}{H}F^2 = 110 \times 39^2 = 167{,}310$, $d = 29$ in.

„ „ BC „ „ $= 110 \times 32^2 = 112{,}640$, $d = 27$ „

„ „ CD „ „ $= 110 \times 10^2 = 11{,}000$, $d = 18$ „

A 29 in. diameter is not a stock size for pipes (being starred on the scale) and a 30 in. diameter will therefore have to be adopted.

2. These diameters would suffice if the velocities in the pipes could be ignored, but they have to be taken into account on the assumption that all taps are open at the same time and all pipes being fully drawn on.

The velocity in a 30 in. pipe discharging 39 cusecs would from formula (xiiA) in the original work, viz.—

$$v = \frac{375F}{2d^2} \quad . \quad . \quad . \quad . \quad . \quad \text{(i)}$$

be $v = \frac{375 \times 39}{2 \times 30^2} = 8{\cdot}1$ ft. per sec., and the safe permissible velocity would from formula (xiv) in the original work, viz.—

$$v' = 0{\cdot}12d + 2 \quad . \quad . \quad . \quad . \quad \text{(ii)}$$

be $v' = 0{\cdot}12 \times 30 + 2 = 5{\cdot}6$ ft. per sec.

The actual velocity is thus considerably greater than the safe permissible velocity, this shows that the hydraulic gradient of 1 in 110 is excessive and will have to be flattened by the introduction of a *break pressure reservoir* (A′) between A and B.

Flattening the gradient will increase the diameter of the supply main.

For a 33 in. main $v = 6{\cdot}7$ ft. per sec., and $v' = 5{\cdot}96$ ft. per sec.

For a 36 in. main $v = 5{\cdot}7$ ft. per sec., and $v' = 6{\cdot}32$ ft. per sec.

A 36 in. pipe will therefore be needed from A′ to B, the required 'average hydraulic gradient' from A′ to 100 ft. above D being, from $\frac{L}{H} \times 39^2 = 547{,}000$, a grade of 1 in 360.

3. The position of the break pressure reservoir can best be ascertained by plotting a longitudinal section of the ground between A and D, and drawing thereon an up grade from 100 ft. above D of 1 in 360.

On the assumption that the fall from A to B is uniform, the reservoir (A′) would have to be placed about 7000 ft. from A with the water level therein at R.L. 242, so as to make the gradient from A′ to 100 ft. above D 42 ft. in 15,000 ft., or 1 in 360.

4. The reduced levels above B and C of this gradient would be, say, 205 and 203 respectively.

The hydraulic gradient from A to A′ will thus be 400 — 242 = 158 ft. in 7,000 ft., or 1 in 44.

The 'average hydraulic gradient' for the two pipes BE and EF will be 205 — 170 = 35 ft. in 2,700 ft., or 1 in 77; the 'actual hydraulic gradient' of the pipe CG, 203 — 190 = 13 ft. in 1,500 ft., or 1 in 116; and of the pipe DG, 200 — 190 = 10 ft. in 1,700 ft., or 1 in 170.

[These would also be the hydraulic gradients from A′ onwards for a 10 ft. surplus head the position of A′, and consequently the hydraulic gradient from A to A′ being alone altered.]

5. From the 'hydraulic gradients' so ascertained and the required discharges values of $\frac{L}{H}F^2$ can be computed for each pipe, and from the values of $\frac{L}{H}F^2$ so deduced the required diameters can be obtained from the full scale.

For clean stock size pipes they are for a 100 ft. surplus head—

As for pipe	AA′	$44 \times 39^2 = 66{,}924$,	$d = 24$ in.
„ „	„ A′B	$360 \times 39^2 = 547{,}000$,	$d = 36$ „
„ „	„ BC	$360 \times 32^2 = 368{,}640$,	$d = 33$ „
„ „	„ CD	$360 \times 10^2 = 36{,}000$,	$d = 22$ „
„ „	„ BE	$77 \times 7^2 = 3{,}773$,	$d = 14$ „

As for pipe EF $77 \times 2^2 = 308$, $d = 9$ in.
„ „ „ CG $116 \times 12^2 = 16{,}704$, $d = 19$ „
„ „ „ DG $170 \times 5^2 = 4{,}250$, $d = 15$ „

6. If 5 galmins (G) have to be supplied to a tap at R.L. 170 in the house H distant 270 ft. from E, the 'hydraulic gradient' for the supply pipe will be 179 — 170 = 9 ft. in 270 ft. or 1 in 30; and from $30 \times 5^2 = 750$ the required diameter from the small inset scale will be $d = 1$ in. For a 40 ft. branch pipe to deliver 2 galmins out of the 5 to a tap in the house at R.L. 150, $\frac{40}{20} \times 2^2$ would equal 8 and $d = \frac{1}{2}$ in.; the 1 in. pipe beyond the branch being from $30 \times 3^2 = 270$ kept at a 1 in. one.

The velocity in the 1 in. pipe when discharging 5 galmins would from formula (xiA) in the original work, viz.—

$$v = \frac{G}{2d^2} \quad . \quad . \quad . \quad . \quad \text{(iii)}$$

be $v = \frac{5}{2 \times 1^2} = 2{\cdot}5$ ft. per sec., and the safe velocity from formula (ii) above—

$$v' = 0{\cdot}12 \times 1 + 2 = 2{\cdot}12 \text{ ft. per sec.}$$

7. Under the above conditions and pipe dimensions the velocities in the three pipes AB, BC and BD will be very near the permissible safe velocities, the velocities in the pipe AA′ and in the distribution pipes will however be a good deal over the safe velocities, and it will therefore be advisable to have these pipes extra thick to guard against damage from 'hydraulic shock,' due to the sudden closing of a valve—or a pressure reducing valve will have to be fixed on each branch, and the sizes of pipes proportionately increased to give the required discharge with decrease in velocity.

To enlarge the pipe diameters without fixing pressure-reducing valves on them would lead to an excessive supply of water where not needed, and would encourage waste.

8. Assuming for the present, however, that the pipes are

strengthened, their diameters to provide against eventual incrustation would be from the full scale—

				stock size
As for pipe AA′	$\frac{L}{H}F^2 =$ 66,924,	$d = 25 + 5$	$= 30$ in.	
„ „ „ A′B	„ $= 547{,}000$,	$d = 36 + 6$	$= 42$ „	
„ „ „ BC	„ $= 368{,}640$,	$d = 34 + 5$	$= 39$ „	
„ „ „ CD	„ $= 36{,}000$,	$d = 22 + 4$	$= 26$ „	
„ „ „ BE	„ $= 3{,}773$,	$d = 13\frac{1}{2} + 2\frac{1}{2}$	$= 16$ „	
„ „ „ EF	„ $= 308$,	$d = 9 + 2$	$= 11$ „	
„ „ „ CG	„ $= 16{,}704$,	$d = 19 + 3$	$= 22$ „	
„ „ „ DG	„ $= 4{,}250$,	$d = 14\frac{1}{2} + 2\frac{1}{2}$	$= 17$ „	
For the small supply house pipes from the inset scale		$d = 1 + \frac{1}{4}$	$= 1\frac{1}{4}$ „	
		$d = \frac{1}{2} + \frac{1}{4}$	$= \frac{3}{4}$ „	

9. With a very flat 'average hydraulic gradient' from A to D, when the velocities in the three pipes AB, BC, CD will be necessarily low, an endeavour should be made to utilise head as far as possible, calculating for *clean* pipes.

Thus with a grade of 1 in 1100 from A to 100 ft. above D or a fall of 20 ft. in 22,000 ft. the value of $\frac{L}{H}F^2$ for the pipe AB will be $1100 \times 39^2 = 1{,}673{,}100$, and d therefore $= 45$ in.

The actual head required in a 45 in. main 20,000 ft. long to discharge 39 cusecs would from $\frac{20000}{H} \times 39^2 = 1{,}750{,}000$ be, $H = 17$ ft., the 'hydraulic gradient' from B to D could thus be steepened from 1 in 1100 to 1 in $\frac{2000}{20 - 17} = 1$ in 667, and the remaining pipe diameters ascertained from this gradient as already explained.

The velocities in the branch pipes would be much the same as before, i.e. above the permissible velocity, and this must always be the case in a distribution system the levels of which vary considerably, as the available head is generally great and the length of pipes relatively small.

10. It will be evident from the above examples that the

PLATE I.

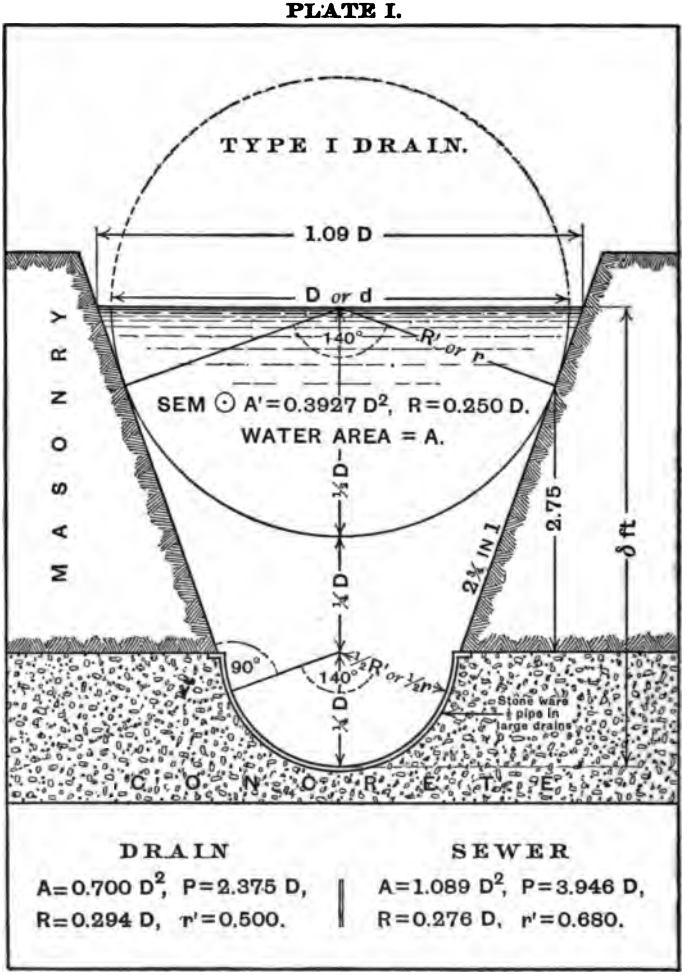
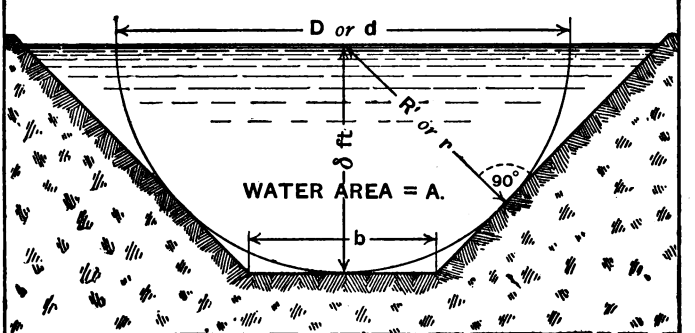

TYPE I DRAIN.
1.09 D
D or d
140°
R' or r'
SEM ⊙ A'=0.3927 D², R=0.250 D.
WATER AREA = A.
MASONRY
½ D
¼ D
¼ D
2¼ IN 1
2.75
6 ft
90°
140°
R' or ½r'
Stone ware pipe in large drains
CONCRETE
DRAIN
A=0.700 D², P=2.375 D,
R=0.294 D, r'=0.500.
SEWER
A=1.089 D², P=3.946 D,
R=0.276 D, r'=0.680.

PLATE II.

TYPE II DRAIN.



SIDE SLOPES

0 TO 1	$A=2\delta^2$	$b=2\delta$	$r'=0.786$
½ " 1	$"=1.74\,\delta^2$	$"=1.24\,\delta$	$"=0.902$
1 " 1	$"=1.83\,\delta^2$	$"=0.83\,\delta$	$"=0.859$
1½" 1	$"=2.11\,\delta^2$	$"=0.61\,\delta$	$"=0.745$
2 " 1	$"=2.47\,\delta^2$	$"=0.47\,\delta$	$"=0.636$
2½" 1	$"=2.89\,\delta^2$	$"=0.39\,\delta$	$"=0.543$
3 " 1	$"=3.33\,\delta^2$	$"=0.33\,\delta$	$"=0.472$

THE HYDRAULIC MEAN DEPTH

(R) always $= \frac{\delta}{2} = \frac{R'}{2}$

required pipe diameters in a water supply scheme, however complicated it may be, can be systematically and accurately ascertained from the accompanying scales, full advantage being taken of all available head and due allowance made, as far as possible, for safe velocities.

The system advocated can be very easily and quickly applied, the small surplus head still available in the distribution pipes being utilised as a reserve to overcome losses of head due to friction in bends and elbows, which so far has not been taken into account, and is in large projects generally a negligible factor.

CHAPTER III

A DRAINAGE PROJECT

THE chief points to keep in view in framing a scheme for draining a given area are--

(i) To secure as many independent outfalls as possible so as to divide the area to be drained into a number of independent drainages.

(ii) To try and obtain for the main, generally central, drains in each independent drainage as steep a gradient in the water surface as possible, also, if this can be arranged for, in the branch drains.

(iii) To adopt a type of drain least expensive to construct. (The two types of drains best suited for this purpose are illustrated in Plates I and II which have been taken from the work mentioned in the preface. Type I is a good one for masonry or concrete drains or sewers and Type II for drains in earth.)

2. Assume now that one of the drainage areas in the tract of land to be drained is that shown in the lower half of Plate III, in which the high flood level at the outfall, the ground levels and the areas of the several valleys to be drained are shown, as well as the drains likely to be needed.

Taking the intensity of run-off with an annual average rainfall of 80 in. to be 1 cusec from each 100,000 sq. ft., an intensity of very nearly $\frac{1}{2}$ in. per hour, the full discharges to be provided for would be—

In drain	H to F	length	4,000 ft.,	discharge	8	cusecs.
„	„ G to F	„	3,600 „	„	7·2	„
„	„ F to D	„	1,200 „	„	15·2	„
„	„ E to D	„	4,400 „	„	10·6	„
„	„ D to B	„	1,600 „	„	25·8	„
„	„ C to B	„	4,000 „	„	6·4	„
„	„ B to A	„	800 „	„	32·2	„

Now if the fall in the ground is taken as the fall in the water surfaces of the central drains H–F–D–B–A and the water surface is kept at least 6 in. below the ground level (except at the very commencement of the drains (H) when it would be the ground level) the 'hydraulic gradients' of the several central drains will be as under—

Drain H to F 110·0 − 103·5 = 6·5 ft. in 4,000 ft. or 1 in 616
„ F to D 103·5 − 101·5 = 2 ft. in 1,200 ft. or 1 in 600
„ D to B 101·5 − 100·5 = 1 ft. in 1,600 ft. or 1 in 1600
„ B to A 100·5 − 100·0 = 0·5 ft. in 800 ft. or 1 in 1600

The flat gradients in the lower reaches would contribute considerably to the cost of these drains as they would have to be large ones.

A better gradient would be one from a point F′ about 1,200 ft. distant from F towards H where the ground level is R.L. 106·5, this would give a fall in the water surface from F′ to A of 106 − 100 = 6ft. in 4,800 ft. or 1 in 800. The reduced levels of this water surface being—

$$\text{At F, } 106{\cdot}0 - \frac{1200}{800} = 104{\cdot}5$$

$$\text{At D, } 104{\cdot}5 - \frac{1200}{800} = 103{\cdot}0$$

$$\text{At B, } 103'0 - \frac{1600}{800} = 101'0$$

$$\text{At A, } 101'0 - \frac{800}{800} = 100'0$$

The adoption of this gradient would involve some earth filling on the outer sides of the drains between F′ and A. The depths of earth filling required so as to have the ground level 6 in. above the water level would be—

At F, 1 ft.	At B, 0ft. 6 in.
At D, 1 ft. 6 in.	At A, nil.

Whether the saving in the cost of drains would meet the cost of the earth filling would have to be worked out; we may, however, assume that it does do so and proceed to ascertain the 'hydraulic gradients' of the remaining drains on the assumption that in each case the fall in the ground is uniform.

The gradient from H to F′ will be—

$110 - 106 = 4$ ft. in 2,800 ft. or 1 in 700

The gradient from G to F will be—

$108 - 104'5 = 3'5$ ft. in 3,600 ft. or say 1 in 1030

The gradient from E to D will be—

$110 - 103 = 7$ ft. in 4,400 ft. or say 1 in 630

The gradient from C to B will be—

$110 - 101 = 9$ ft. in 4,000 ft. or say 1 in 445

The 'hydraulic gradients' in the several drains having been thus determined the dimensions of the drains can be ascertained for the types illustrated in Plates I and II from the 'full scale' as shown in paragraph 5 below.

3. The 'hydraulic mean depth' of a drain is denoted on the plates by R and is—

$$R = \frac{\text{The wetted area of the drain in square feet}}{\text{The wetted perimeter of the drain in feet}} = \frac{A}{P}$$

r' on the plates is a 'discharge reduction coefficient,' the use of which is explained later on, deduced from a consideration of the proportion which the area of a circle or semicircle inscribed in the drain or sewer section bears to the area of the entire drain or sewer, due allowance, as explained in the original work, being made for the actual velocity in such drain or sewer compared with what would be under similar conditions the actual velocity in the circular or semicircular area if it had with a similar interior surface—in other words to which the same coefficient would apply.

The values of r' shown on Plates I and II have been deduced in the case of the drains from the inscribed semicircles, and in the case of the sewer from the inscribed circle. D being in each case the diameter in feet, and d in inches.

If we imagine a circle diameter $= \frac{1}{2}d$, equal say d' for convenience, inscribed in the lower end of the drain illustrated in Plate I, then the values of A, P, and R, and of r' (deduced from such a circle) will be—

For a full drain—
$A = 0{\cdot}700D^2$ $P = 2{\cdot}375D$ $R = 0{\cdot}294D$ $r' = 0{\cdot}15$

For a $\frac{3}{4}$ drain—
$A = 0{\cdot}454D^2$ $P = 1{\cdot}845D$ $R = 0{\cdot}246D$ $r' = 0{\cdot}25$

For a $\frac{1}{2}$ drain—
$A = 0{\cdot}252D^2$ $P = 1{\cdot}315D$ $R = 0{\cdot}192D$ $r' = 0{\cdot}55$

For a $\frac{1}{4}$ drain—
$A = 0{\cdot}100D^2$ $P = 0{\cdot}786D$ $R = 0{\cdot}127D$ $r' = 2{\cdot}0$

Whence the relative velocities are as 100 : 87 : 75 : 55, and the relative discharging capacities as 100 : 56 : 27 : 8, or more roughly as $1 : \frac{8}{5} : \frac{1}{4} : \frac{1}{12}$.

If, again, we imagine a circle with diameter $= \frac{1}{2}d =$ say d' inscribed in the centre of a type II drain, the values of r' deduced from such a circle will be—

When the side slopes are 0 to 1, $r' = 0{\cdot}23$
" " " " " $\frac{1}{2}$ to 1, $r' = 0{\cdot}27$
" " " " " 1 to 1, $r' = 0{\cdot}25$

When the side slopes are $1\frac{1}{2}$ to 1, $r' = 0{\cdot}22$
" " " " " 2 to 1, $r' = 0{\cdot}19$
" " " " " $2\frac{1}{2}$ to 1, $r' = 0{\cdot}17$
" " " " " 3 to 1, $r' = 0{\cdot}15$

4. Before proceeding to show how the dimensions of the drains required in the drainage system at present under consideration can be ascertained from the accompanying scales, it will be as well to demonstrate that the scales can be relied on as well as to explain how they are to be used.

It has been shown in the author's 'The Precise Calculation of Pipe Drain and Sewer Dimensions,' that the depth of a full masonry or concrete drain on type I would for Kutter's $n = 0{\cdot}013$ be 40 in. for a required discharge of 21 cusecs, the slope in the water surface being 1 in 1764 as for such a drain $\frac{L}{H}F^2 = 1764 \times 21^2 = 777{,}924$.

Now to ascertain the value of d', the diameter of the lower circle, in a full drain we should have to reduce the required discharge from 21 cusecs to $21 \times r'$ cusecs $= 21 \times 0{\cdot}15$ cusecs $= 3{\cdot}15$ cusecs, and as for a circle the value of $\frac{L}{H}F^2$ would be $1764 \times (3{\cdot}15)^2 = 17{,}640$ the value of d' for Kutter's $n = 0{\cdot}013$ will from the full scale be $19 + 1 = 20$ in.; and as $d = 2d'$, d will, as previously ascertained, be 40 in.

For a drain in earth on type II, with side slopes of 1 to 1 to discharge 21 cusecs with a slope in the water surface of 1 in 1764, the depths of the drains for the undermentioned coefficients were found from the Tables in the original work to be—

For Bazin (i) . . $\delta = 2{\cdot}6$ ft. $= 2$ ft. $7\frac{1}{4}$ in.
" Kutter's $n = 0{\cdot}025$, $\delta = 2{\cdot}7$ ft. $= 2$ ft. $8\frac{1}{2}$ in.
" " (ii) . . $\delta = 2{\cdot}8$ ft. $= 2$ ft. $9\frac{1}{2}$ in.

To find the required depths (d' or δ) from the imaginary inscribed central circle in a type II drain we have

from the full scale as $r' = 0{\cdot}25$, whence $21 \times 0{\cdot}25 = 5{\cdot}25$ and $\frac{L}{H}F^2 = 1764 \times (5{\cdot}25)^2 = 48{,}510$, for—

Bazin (i) . . $d' = 23 + 7 = 30$ in., whence $\delta = 2$ ft. 6 in.
Kutter's $n = 0{\cdot}025$ $d' = 23 + 9 = 32$ in., whence $\delta = 2$ ft. 8 in.
Bazin (ii) . . $d' = 23 + 11 = 34$ in., whence $\delta = 2$ ft. 10 in.

The required depths being in each case practically identical.

For a drain in earth on type II with side slopes of 1 to 1 and $n = 0{\cdot}025$ to discharge 200 cusecs with a slope in the water surface of 1 in 4000 the required depth was from the Tables in the original work found to be 7·1 ft.

As for a drain in earth on type II with side slopes of 1 to 1 the value of r' derived from the inscribed circle diameter $d' = 0{\cdot}25$, $200 \times 0{\cdot}25$ will $= 50$, and as $4000 \times 50^2 = 10{,}000{,}000$, the required depth of drain in inches (d') from the full scale will $= 63 + 22 = 85$ in., whence $\delta = 7$ ft. 1 in., an exact agreement.

5. Calculating now for the drains required in the drainage scheme under consideration, allowing for drains in earth with side slopes of 1 to 1 and using as coefficient Kutter's $n = 0{\cdot}025$, we have, taking the discharge of the drain HF′ at $\frac{2800}{4000} \times 8 =$ say 6 cusecs—

For drain HF′—
$700 \times (6 \times 0{\cdot}25)^2 = 1{,}575$, and $d' = 12 + 5 = 17$ in.
For drain F′F—
$800 \times (8 \times 0{\cdot}25)^2 = 3{,}200$, and $d' = 14 + 6 = 20$ in.
For drain FD—
$800 \times (15{\cdot}2 \times 0{\cdot}25)^2 = 11{,}552$, and $d' = 18 + 7 = 25$ in.
For drain DB—
$800 \times (25{\cdot}8 \times 0{\cdot}25)^2 = 33{,}282$, and $d' = 21 + 8 = 29$ in.
For drain BA—
$800 \times (32{\cdot}2 \times 0{\cdot}25)^2 = 51{,}842$, and $d' = 23 + 9 = 32$ in.
For drain GF—
$1030 \times (7{\cdot}2 \times 0{\cdot}25)^2 = 3{,}337$, and $d' = 14 + 6 = 20$ in.

For drain ED—

$630 \times (10{\cdot}6 \times 0{\cdot}25)^2 = 4{,}420$, and $d' = 15 + 6 = 21$ in.

For drain CB—

$445 \times (6{\cdot}4 \times 0{\cdot}25)^2 = 1{,}139$, and $d' = 11 + 5 = 16$ in.

For a full type I masonry or concrete drain with $n = 0{\cdot}013$ the required depth d for the drain BA would, from $\frac{L}{H}F^2 = 800 \times (32{\cdot}2)^2 = 829{,}472$ using the full scale, be $39 + 1 = 40$ in.; also using the value of r' derived from the inscribed circle diameter d', i.e. $r' = 0{\cdot}15$, as $\frac{L}{H}F^2 = 800 \times (32{\cdot}2 \times 0{\cdot}15)^2 = 18{,}664$, d' will $= 19 + 1 = 20$ in., whence $d = 2d'$ would $= 40$ in., as above ascertained, and δ therefore $=$ 3 ft. 4 in.

If lined with—

ordinary plaster the depth of the drain would be 39 in.
mixed cement „ „ „ „ „ „ „ 39—1 = 38 in.
pure cement „ „ „ „ „ „ „ 39—3 = 36 in.

Full drains on type I are, however, not well suited to small discharges and half a type I drain will answer better in such cases and may even, if so desired, be used for large discharges.

As r' the 'discharge reduction coefficient' to ascertain d' for a half drain on type I is 0·55 we should for drain BA have $800 \times (32{\cdot}2 \times 0{\cdot}55)^2 = 251{,}000$ and $d' = 31 + 1 = 32$ in., this would be the depth of the drain also, whence $\delta = 2$ ft. 8 in.

If the drain is lined with—

plaster the depth would be 31 in.
mixed cement „ „ „ 31 — 1 = 30 in.
pure cement „ „ „ 31 — 2 = 29 „

A drain with less depth 32 in. against 40 in. but with a wider base radius 16 in. in place of 10 in. being thus secured.

For side slopes other than $2\frac{3}{4}$ to 1 the values of r' for a drain d' inches in depth are—

vertical $r' = 0{\cdot}65$, also the area in sq. ft. $A = 0{\cdot}89\delta^2$
2 to 1 $r' = 0{\cdot}53$, „ „ „ „ $= 1{\cdot}06\delta^2$
$1\frac{1}{2}$ to 1 $r' = 0{\cdot}45$, „ „ „ „ $= 1{\cdot}21\delta^2$
1 to 1 $r' = 0{\cdot}40$, „ „ „ „ $= 1{\cdot}38\delta^2$

drain with side slopes of 1 to 1, $32{\cdot}2 \times 0{\cdot}40 = 13$
$0 \times 13^2 = 135{,}200$, $d' = 28 + 1 = 29$ in. and
in.

dimensions of the drains being thus ascertained the
n them have to be next considered.
ea of a type II drain would for the drain BA be
$\cdot 83 \left(\frac{32}{12}\right)^2 = 13{\cdot}0$ sq. ft. and as the discharge is
s the velocity will be $\frac{32{\cdot}2}{13{\cdot}0} = 2{\cdot}4$ ft. per sec., which
e generally accepted safe velocity for drains in earth
sec. Calculated from formula (i) above, allowing
d velocity—

$$= \frac{375 \times (32{\cdot}2 \times 0{\cdot}25)}{2 \times 32} \times \frac{0{\cdot}7854\delta^2}{1{\cdot}83\delta^2} \times \frac{1}{0{\cdot}25}$$

$$= 1{\cdot}44 \times \frac{0{\cdot}43}{0{\cdot}25} = 2{\cdot}4 \text{ ft. per sec. also.}$$

a of a full section masonry or concrete drain on type I
will be $0{\cdot}700D^2 = 0{\cdot}700 \times (3{\cdot}33)^2 = 7{\cdot}8$ sq. ft., and
y therefore $\frac{32{\cdot}2}{7{\cdot}8} = 4{\cdot}12$ ft. per sec.; this again is
safe velocity of 5 ft. per sec. for masonry or con-
s. The area of a half type I drain 32 in. deep ($D =$
$= 0{\cdot}252\,D^2 = 7{\cdot}2$ sq. ft. and $v = \frac{32{\cdot}2}{7{\cdot}2} = 4{\cdot}5$ ft. per sec.
drain depth $d' = 29$ in., with side slopes of 1 to 1 $A =$
$1{\cdot}38 \times \left(\frac{29}{12}\right)^2 = 8{\cdot}1$ sq. ft. and $v = \frac{32{\cdot}2}{8{\cdot}1} = 4$ ft.
oth of which velocities are below the safe limit.
e actual velocities been in excess of the safe velocities
ave been necessary to calculate the slope to suit the
section required to keep down the velocity to the

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for use with full Scale.

desired limit by providing falls at suitable points. This slope can be ascertained from the original general formula (ii) viz. —

$$v = C\sqrt{R}\sqrt{S} = C\sqrt{R}\,\frac{1}{\sqrt{L}}, \text{ when } H = 1 \quad . \quad \text{(iv)}$$

For the drain BA in earth velocity 2·4 ft. per sec. we have—

$$2{\cdot}4 = C\sqrt{R} \times \frac{1}{\sqrt{800}}$$

whence $C\sqrt{R} = 67{\cdot}9$

For a velocity of 3 ft. per sec. as the value of $C\sqrt{R}$ will vary very slightly with variation in the slope—

$$3 = 67{\cdot}9 \times \frac{1}{\sqrt{L}}$$

$\therefore \quad \sqrt{L} = 22{\cdot}6$

or squaring $\quad L = 511$

For the full masonry drain velocity 4·12 ft. per sec.—

$$4{\cdot}12 = C\sqrt{R} \times \frac{1}{\sqrt{800}}$$

$\therefore \quad C\sqrt{R} = 116{\cdot}6$

and as $\quad 5 = 116{\cdot}6 \times \frac{1}{\sqrt{L}}$

$\therefore \quad \sqrt{L} = 23{\cdot}3$

whence $\quad L = 543$

The slope in the water surface could therefore safely be in either case steepened from 1 in 800 to 1 in 550 without the velocity being in excess.

7. If the drain BA is to be an arched (dotted line) sewer on type I, $r' = 0{\cdot}68$ and as $32{\cdot}2 \times 0{\cdot}68 =$ say 22, $\frac{L}{H}F^2 = 800 \times 22^2 = 387{,}200$, whence d (for Kutter's $n = 0{\cdot}013$) $= 34 + 1 = 35$ in.; for Kutter's $n = 0{\cdot}010$, $d = 34 - 3 = 31$ in.

The area of the sewer would from $A = 1{\cdot}089D^2 = 9{\cdot}2$ sq. ft., and $v = \frac{32{\cdot}2}{9{\cdot}2} = 3{\cdot}5$ ft. per sec.

8. When the depth of a drain in earth on type II exceeds 6 ft. it will generally be advisable to modify the type so as to keep the depth down to 6 ft.

This can be done very approximately in the following way.

Suppose that the required depth of a drain on type II with side slopes of 1 to 1 is found to be 8 ft. then

$$A = 1{\cdot}83\delta^2 = 117 \text{ sq. ft.}$$
$$b = 0{\cdot}83\delta = 6{\cdot}7 \text{ ft.}$$
$$R = \frac{8}{2} = 4$$

If the depth is reduced to 6 ft. and the side slopes are kept at 1 to 1, then for the same area $6(b + 6) = 117$, and $b = 13{\cdot}5$ ft., also $R = \frac{A}{P} = \frac{117}{17 + 13{\cdot}} = 3{\cdot}8$ say.

It will therefore be necessary to increase the area of the drain, i.e. to have b greater than 13·5. Taking it at 14 ft. $A = 6(14 + 6) = 120$ sq. ft., and $R = \frac{120}{31} = 3{\cdot}9$, and a drain of these dimensions would most probably meet requirements, as with $R = 4$, $\frac{6(b + 6)}{b + 17} = 4$, whence $b = 16$ ft. and $A =$ 132 sq. ft., which is excessive, as an area of 117 sq. ft. with $R = 4$ will give the required discharge.

The exact value of b can be ascertained from the Tables in the original work.

9. It has been assumed above that the entire discharge to be provided for in a drain flows into it at once; this of course is not the case, there will be a gradual increase in the flow of an open drain from its commencement to its outfall. Thus in the case of the 4,400 ft. long drain ED, total required discharge 10·6 cusecs, we may assume the discharge to be 1 cusec in the first 400 ft., two cusecs in the second 400 ft., and so on.

The required depths to water surface for drains in earth